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(54) ELECTRO-CHEMICAL MACHINING

(71) We, T. I. (GROUP SERVICES) LIMITED, a British Company, of T. I. House, Five Ways, Edgbaston, Birmingham, 16, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a method of, and apparatus for, finishing the machining of a gearwheel.

Conventional gearwheel finishing techniques comprise mechanical machining processes such as shaving, ironing and honing. According to the present invention we propose to finish gearwheels by applying electro-chemical machining techniques.

The present invention consists in a method of finishing the machining of a gearwheel comprising providing a tool in the form of a gearwheel which has flanks of its teeth each provided with a layer of dispersed particulate electrically non-conducting material which extends above the surface of the flank by an amount that varies in a predetermined manner along the flank; rotating this tool gearwheel at constant speed in mesh with the gearwheel which is to be finished so that the layers of material on the flanks of the teeth of the tool gearwheel engage successive flanks of the teeth of the gearwheel which is to be finished and space the flanks apart by a distance which varies with the thickness of said layer of material at the point of driving engagement of the flanks, this variation in thickness being such that the spacing of the flanks at their point of driving engagement decreases along the flanks as the speed of their point of driving engagement increases along the flanks; supplying a stream of electrolyte between the meshing teeth; and applying a voltage between the two gearwheels so that the tool gearwheel is made the cathode and the gearwheel to be finished is made the anode in an electro-chemical machining process whereby metal is removed from the flanks of the teeth of the gearwheel to be finished at a substantially constant rate along their length.

The dispersed particulate electrically non-conducting material on the flanks of the tool gearwheel allows the two gearwheels to mesh in driving engagement but prevents electrical shorting which would stop the electro-chemical machining process. Preferably, this material has an abrasive quality so that it aids removal of chemical products from the gearwheel being finished so as to maintain the electro-chemical machining process.

The predetermined variation in thickness of the layers of material along the flanks produces a corresponding variation in the spacing or machining gap at the point of driving engagement between the teeth as this point moves along the flanks and thereby produces a corresponding variation in the machining rate which is such as to counteract the basic variation in the machining rate resulting from the involute form of the teeth which causes the speed of the point of driving engagement to vary along the flanks. The speed of this point increases along the flank of each tooth causing a corresponding decrease in the machining rate which is therefore counteracted by decreasing the thickness of the layers along the flanks of each tooth of the tool gearwheel in the direction of movement of the point of driving engagement.

A tool gearwheel having teeth each with a layer of material of suitably varying thickness along its flanks is most easily produced by embedding said material in the flanks of the teeth of the tool gearwheed so that the metal of the flanks serves as a supporting matrix and a layer of said material of substantially uniform thickness extends above the surface of the metal matrix, rotating the tool gearwheel at a constant speed in driving mesh with a master gearwheel of exactly similar dimensions to the gearwheel which the tool gearwheel is to finish, supplying a stream of electrolyte between the meshing teeth, and applying a

voltage between the two gearwheels so that the master gearwheel is made the cathode and the tool gearwheel is made the anode and an appropriate depth of the metal matrix surrounding the dispersed particles of said material along the flanks of the teeth of the tool gearwheel is removed so as to expose more of the particles and increase the thickness of the layer above the surface of the metal matrix.

In this machining process the tool gearwheel thus becomes the work gearwheel and the tool gearwheel proper is a hardened master gearwheel of the same form as the gearwheels which are to be finished by the final tool gearwheel. The machining process automatically removes the amount of the metal matrix to produce the required thickness of the material along the flanks of the teeth. The finished tool gearwheel is then used to finish work gearwheels which mesh with the tool gearwheel in exactly the same way as the master gearwheel meshed with the tool gearwheel.

The method of finishing the machining of a gearwheel according to the invention can replace the conventional shaving, ironing and honing gear finishing processes, it allowing a higher rate of metal removal than these conventional process without degrading the profile of the teeth or producing a rough finish. Further, the method according to the invention can be used to finish the machining of pre-cut or pre-rolled gearwheels, either in the hardened or unhardened state.

The invention is now described by way of example with reference to the accompanying drawings in which:—

Figure 1 is a schematic drawing showing a gearwheel being finished by the method according to the invention,

Figure 2 is a cross-sectional view along the line 2—2 of Figure 1, and

Figure 3 is a schematic view showing how a tool gearwheel such as shown in Figures 1 and 2 is formed.

Figures 1 and 2 show a work gearwheel W to be finished which is meshed with a tool gearwheel T of substantially similar dimensions, both gearwheels being keyed on respective parallel shafts S to rotate therewith. The tool gearwheel T is provided with a layer of dispersed particulate electrically non-conducting material such as an abrasive diamond or aluminium oxide deposit, of varying thickness around the edges of its teeth as further described below, which allows the teeth of both gearwheels to mesh in driving engagement but which prevents electrical contact between these teeth. The tool gearwheel T is rotated at a constant speed which causes the work gearwheel W to rotate at the same speed, the sense of rotation of both gearwheels being shown by arrows in Figure 2, and an electro-chemical machining action is produced at the points of driving engagement D between the meshing teeth of the gearwheels by directing high pressure streams of electrolyte from jet nozzles J at both sides of the meshing teeth and applying a d.c. voltage between the two gearwheels which makes the tool gearwheel T the cathode and the work gearwheel W the anode, the electro-chemical action removing metal from the edges of the teeth of the work gearwheel W.

Typically, gearwheels of diameter 2.5 inches and with 30 teeth are rotated at a speed of 500 revolutions per minute, the electrolyte is a neutral salt electrolyte having a conductivity of 0.15 mhos per centimetre and supplied at a pressure of 100 pounds per square inch, and the d.c. voltage is 8 volts. The corresponding machining rate which is produced is about 0.001 to 0.002 inches per minute per flank.

The electro-chemical machining rate at the points of driving engagement D is dependent on the speed with which these points D move along the flanks of the teeth as the gearwheels rotate, and also on the spacing or machining gap at these points as defined by the mean height of the tips of the abrasive diamond deposit above the supporting metal matrix of the flanks of teeth on the tool gearwheel T. The speed of the points D along the flanks will vary in the usual way due to the involute profile of the teeth of the gearwheels, the speed of each point D increasing as it moves along the flanks, and if not compensated for this would cause a corresponding change in the machining rate. Thus, the machining rate at the points D would decrease as these points move towards the root of the teeth on gearwheel W and the required involute form of these teeth would be degraded. To prevent this from happening the thickness of the diamond deposit along the edge of each tooth of the gearwheel T is varied so as to produce a variation in the machining gap at the points D as they move along the flanks which affects the machining rate in the opposite sense to the variations in the speed of the points D and thereby produces a constant machining rate. Thus, the thickness of the diamond deposit on the flanks of the teeth of the gearwheel T decreases towards the tips of the teeth so that the machining gap at the points D decreases in time as the speed of these points increases.

The required variation in the thickness of the diamond deposit on the teeth of the tool gearwheel T is preferably produced by forming the tool gearwheel with a diamond deposit of uniform thickness and then using the electro-chemical gear finishing process of the present invention to remove an appropriate depth of the supoprting metal matrix so as to expose more of the diamond de-

posit and thereby increase its thickness relative to the surface of the metal matrix. The finishing process involves making the tool gearwheel T the anode and rotating it in mesh with a hardened master gearwheel exactly similar dimensions to the work gearwheel W. Figure 3 shows how the metal matrix along the flank of a tooth of the tool gearwheel T is machined using a master gearwheel M, the general arrangement being as shown in Figures 1 and 2 but with the gearwheel M in place of the gearwheel W and the polarity of the d.c. voltage reversed. As already described above the speed of the points of driving engagement D^1 will increase towards the tip of the tooth on the tool gearwheel T and will cause a corresponding decrease in the amount of the metal matrix removed so that the surface of the metal matrix is machined to the tapered form E and the mean thickness of the diamond deposit decreases towards the tip of the tooth, as required. Thus, this finishing process automatically produces a tool gearwheel with the desired variation in the thickness of the diamond deposit.

In the description so far we have only referred to electro-chemical machining at the points of driving engagement D on the trailing flanks of the teeth of the work gearwheel. This may, in fact, be the only electro-chemical machining which occurs if the teeth of the gearwheel T do not come into rolling engagement with the leading flanks of the teeth of the work gearwheel W. In this case the leading flanks of the teeth of the work gearwheel W have to be finished in a separate operation. This can be done either by turning one or the other of the gearwheels around or, if the same variation in thickness of the diamond deposit is provided on both flanks of each tooth of the tool gearwheel T, by simply reversing the sense of rotation of the gearwheels. It is also possible, however, to arrange that points on opposite flanks of each tooth of the gearwheel T engage adjacent flanks of adjacent teeth of the gearwheel W whereupon both sets of flanks of the work gearwheel W are finished in one operation. The required variation in thickness of the diamond deposit on leading and trailing flanks of a tooth of the tool gearwheel will not be the same, the thickness increasing towards the tip on a trailing flank and decreasing towards the tip on a leading flank. This variation in thickness can still be obtained using a master gearwheel and the electro-chemical finishing process.

It is important that the flow of electrolyte in the region of the meshing teeth of the gearwheel is sufficient to carry both heat and chemical by-products, produced by the electro-chemical action, away from the meshing teeth so that the electro-chemical action is not impaired. A difficulty in ensuring an adequate flow of electrolyte is often the generation of a gas as a by-product, such as hydrogen with aqueous electrolytes, which physically impedes the flow of electrolyte. The illustrated arrangement for supplying jets of electrolyte is particularly efficient in this respect.

In alternative embodiments of the invention it may be sufficient simply to submerge both gearwheels, or at least the region of the meshing teeth, in electrolyte. In other embodiments the form of the tool gearwheel may be modified to aid the flow of electrolyte. Thus, this gearwheel may be split in a plane perpendicular to its axis of rotation so as to allow electrolyte to be supplied under pressure between the two portions thereof to the engaging teeth. This split gearwheel may further be oscillated bodily along its axis as it rotates in order to aid the flow of electrolyte and ensure machining of the region between the two portions thereof.

The number of teeth of the two gearwheels which are simultaneously in mesh alternately increases and decreases by one and causes variation in the demand for current from the power supply applying the d.c. voltage between the gearwheels. It is, therefore, preferable to use a constant voltage power supply with a sufficiently rapid response characteristic to be able to follow the changing electrical load resulting from the variation in the number of teeth simultaneously in mesh. This last feature may be particularly important where the speed of rotation of the gearwheels is high, which may be the case, to overcome arcing between teeth when they disengage.

In the illustrated embodiment of the invention the tool gearwheel is driven and this causes the work gearwheel to rotate. In alternative embodiments of the invention, however, the work gearwheel may be driven so as to rotate the tool gearwheel. Clearly, in these alternative embodiments, if the dimensions of the gearwheels are such that electro-chemical machining occurs only along one set of flanks of the gearwheels, these flanks will be the engaging trailing flanks of the tool gearwheel and leading flanks of the work gearwheel.

WHAT WE CLAIM IS:—

1. A method of finishing the machining of a gearwheel, comprising providing a tool in the form of a gearwheel which has flanks of its teeth each provided with a layer of dispersed particulate electrically non-conducting material which extends above the surface of the flank by an amount that varies in a predetermined manner along the flank; rotating this tool gearwheel at constant speed in mesh with the gearwheel which

is to be finished so that the layers of material on the flanks of the teeth of the tool gearwheel engage successive flanks of the teeth of the gearwheel which is to be finished and space the flanks apart by a distance which varies with the thickness of said layer of material at the point of driving engagement of the flanks, this variation in thickness being such that the spacing of the flanks at their point of driving engagement decreases along the flanks as the speed of their point of driving engagement increases along the flanks; supplying a stream of electrolyte between the meshing teeth; and applying a voltage between the two gearwheels so that the tool gearwheel is made the cathode and the gearwheel to be finished is made the anode in an electro-chemical machining process whereby metal is removed from the flanks of the teeth of the gearwheel to be finished at a substantially constant rate along their length.

2. A method as claimed in claim 1 in which the teeth of the two gearwheels are of dimensions such that the electro-chemical machining process occurs along only one set of flanks of the teeth of the gearwheel being finished, which set of flanks may be the leading or trailing flanks, the other set of flanks being finished in the same manner but in a separate operation.

3. A method as claimed in claim 2 in which only said one set of flanks of the teeth of the tool gearwheel are provided with said layers of material, and in which one of the gearwheels is turned round to interchange its leading and trailing flanks for said separate finishing operation on said other set of flanks.

4. A method as claimed in claim 2 in which both sets of flanks of the teeth of the tool gearwheel are provided with said layers of material, which vary in thickness in the same predetermined manner from the root to the tip of the flanks of each set and in which the sense of rotation of the two gearwheels is reversed for said separate finishing operation on the other set of flanks.

5. A method as claimed in claim 1 in which the teeth of the two gearwheels are of dimensions such that the electro-chemical machining process occurs simultaneously along both sets of flanks of the tool gearwheel being provided with said layers of material and the thickness of the layers on one set of flanks varying in thickness from root to tip in the opposite sense to the variation in thickness of the layers on the other set of flanks.

6. A method as claimed in claim 2, 3 or 5 in which the flanks of the teeth of the gearwheels are of involute shape and in which any layers of material on the leading flanks of the tool gearwheel decrease in thickness from the root to the tip and any layers of material on the trailing flanks of the tool gearwheel increase in thickness from the root to the tip.

7. A method as claimed in any of the preceding claims in which the tool gearwheel drives the gearwheel being finished.

8. A method as claimed in any of the preceding claims in which the tool gearwheel and gearwheel being finished are of substantially similar dimensions.

9. A method as claimed in any of the preceding claims in which jets of electrolyte are directed from both sides of the meshing gearwheels at their meshing teeth.

10. A method as claimed in any of the preceding claims in which the particulate electrically non-conducting material has an abrasive quality so that it helps remove metal from the flanks of the gearwheel being finished by an abrasive action.

11. A tool in the form of a gearwheel which is to be used for finishing the machining of a gearwheel in an electro-chemical metal removal process in which it is rotated in mesh with the gearwheel being finished and is made an electrode, the tool gearwheel having flanks of its teeth each provided with a layer of dispersed particulate electrically non-conducting material which, in use is to engage the flanks of the gearwheel of the gearwheel being finished and space the respective flanks apart, and which varies in thickness along the length of each flank in a predetermined manner so that in use the spacing of the flanks at their point of driving engagement decreases along the flanks as the speed of their point of driving engagement increases along the flanks thereby resulting in a substantially constant rate of removal of metal along the flanks of the gearwheel to be finished.

12. A tool as claimed in claim 11 in which only one set of flanks of the teeth of the gearwheel are provided with said layers of material.

13. A tool as claimed in claim 11 in which both sets of flanks of the teeth of the gearwheel are provided with said layers of material.

14. A tool as claimed in claim 13 in which the thickness of said layer of material on both sets of flanks varies in the same predetermined manner from root to tip.

15. A tool as claimed in claim 13 in which the thickness of said layers of material on one set of flanks varies from root to tip in the opposite sense to the variation of thickness from root to tip of said layers of material on the other set of flanks.

16. A tool as claimed in any one of claims 11 to 15 in which the flanks of the teeth are of involute shape and in which any layers of material on those flanks which are to be leading flanks in use decrease in

)f said material along the flanks of
th of the tool gearwheel is removed
) expose more of the particles and in-
the thickness of the layer above the
of the metal matrix.

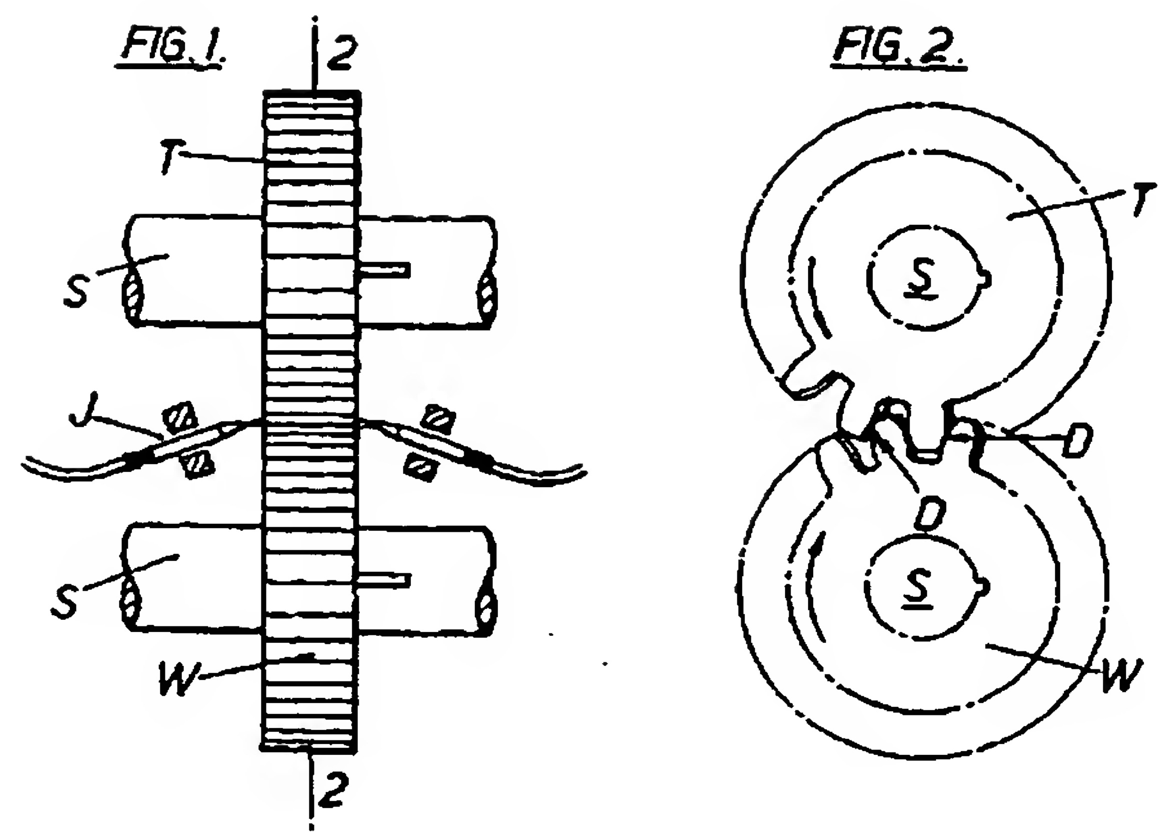
A method as claimed in claim 18 in
jets of electrolyte are directed from
des of the meshing gearwheels at their
g teeth.

A method of finishing the machining
earwheel substantially as herein de-
with reference to the accompany-
wings.

A tool in the form of a gearwheel
s to be used for finishing the machin-
a gearwheel as claimed in claim 11

1346174 COMPLETE SPECIFICATION

1 SHEET *This drawing is a reproduction of the Original on a reduced scale*



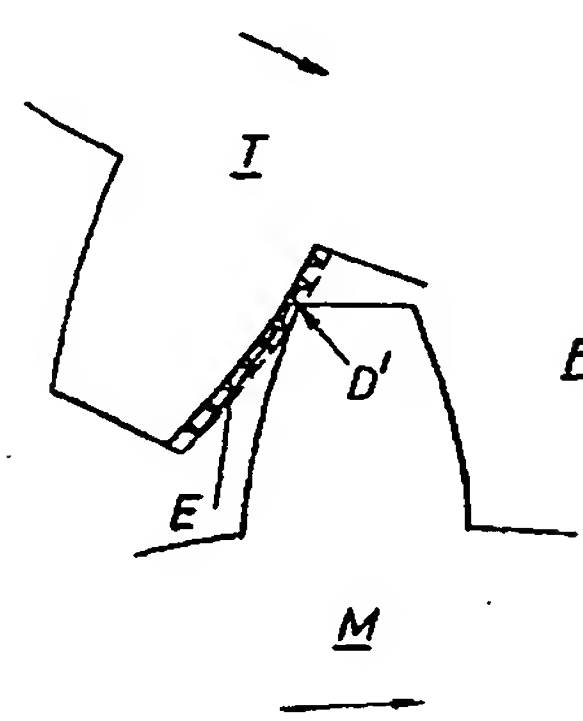


FIG. 3.